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CONFERENCE PROCEEDINGS

For The

NFPCA REGULATORY IMPACT PROGRAMS CONFERENCE

USFA Grant #NFPCA-78052

Held At

Penn Harris Motor Inn
Camp Hill, Pennsylvania

On

19 and 20 July 1978

Proceedings Prepared

January 11, 1979

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ABSTRACT

The purpose of the Conference was to allow presentation of work from NFPCA grantees to the fire community and to permit open discussions of the fire protection systems concepts. A panel and workshop was used to encourage productive interaction among attendees.

The Conference was coordinated with the NFPA Committee on Systems Concepts for Fire Protection in Structures so that members of that Committee could also attend the Regulatory Impact Program Conference.

The principals involved were:

Dr. Joseph E. Clark, NFPCA	Chairman
Mr. John B. Ferguson, NFPCA	NFPCA Coordinator
Mr. Joseph A. Swartz, NFPA	Conference Coordinator
Ms. Joanne C. Oliver, PMA, Inc.	Conference Arrangements

The Proceeding Editors were:

Mr. Joseph A. Swartz, NFPA

Mr. Edward M. Connelly, PMA, Inc.

EDITORS' PREFACE

The presentors at the Camp Hill Conference are in various stages of their grants, some have completed their programs and reported their final results, others are in mid-stream and reported tentative results, and still others are just beginning their work and reported research plans. As a result of this mixed research status, some presentation materials are more complete than others as is evidenced by the enclosed papers.

The overlapping status and mutually supportive nature of the research efforts led to much of the force of the Camp Hill Conference. Both speakers and attendees had the opportunity to review the work completed, as well as work planned, and to provide critical questioning of completed work and objective comments on work in progress. Presentors, likewise, had an opportunity to field and answer questions regarding their work, and also, especially those whose work is in progress, had the benefit of the insight of the attendees in planning their work efforts and reporting the work in the future. The spirit of the Camp Hill Conference, therefore, was one of cooperation among the attendees and the presentors to discuss and understand results as well as to influence ongoing research.

The editors have taken some editorial license in order to make the individual papers more closely similar in editorial style. This has not always been possible due to the very preliminary through completion stages of the various studies that were reported upon. For technical content and merit, we thank the speakers. For any errors which might have crept in during the editing, we apologize to both speakers and readers.

Without the energetic and dedicated administrative and technical support of Dr. Joe Clark, John Ferguson, and Howard Markman of the U.S. Fire Administration, this excellent conference would not have been pulled together in so short a period of time. Without the constant attention to detail of Joanne Oliver of Performance Measurement Associates, Inc., the excellent arrangements would not have been possible. Without the typing and administrative support of Jan DelTergo of NFPA, the Conference and the Proceedings would not have been completed.

For making this Conference a truly stimulating learning experience, we give special thanks to the attendees for their lively and informative comments and discussions.

Joseph A. Swartz, NFPA
Edward M. Connelly, PMA

A MODERN APPROACH TO
BUILDING FIRESAFETY:
THEORY AND PRACTICE

Interim Presentation

D. Peter Lund	Society of Fire Protection Engineers
Robert W. Fitzgerald	Worcester Polytechnic Institute
Rolf H. Jensen	Rolf Jensen & Associates, Inc.
Rexford Wilson	Firepro, Inc.

Grant NFPCA-77048

The Challenge: Identifiable fire protection engineering methods for the design and evaluation of building fire safety exist today. These systems approaches utilize an organizational framework that allows the state-of-the-art of the existing building and fire safety technology to be incorporated. When applied objectively, certain quantitative analyses can be used which in turn depend upon the data base. Brief descriptions of these methods are recorded in certain publications. Practitioners have developed their own subtle variation; some recorded, some not. A limited number of technical papers have been presented on the subject. A multitude of discussions, both formal and informal, have been held. Yet, no single volume which collects the current body of knowledge in fire protection engineering and describes how to use the systems exists.

With this background, the Society of Fire Protection Engineers sought and received in the Fall of 1977 a grant from the National Fire Prevention and Control Administration to gather together the current body of knowledge in fire protection engineering and to document the fundamental design and evaluation methods in book form. The project is divided into two phases - IA and IB. Phase IA is completed. It involved the creation of a detailed outline of the book, the development of a preface and three chapters. Also included was the beginning of a fire terminology glossary which will be expanded as time progresses. Phase IB funding is predicated upon acceptance of the Phase IA product by the NFPCA.

Product: The system approaches to be documented have evolved since 1971 and are essentially based upon Appendix D of PBS 5920.9 "Building Fire Safety Criteria" entitled "Interim Guide to Goal-Oriented Systems Approach to Building Firesafety." This document has the following major features:

1. The concept of relative risk. Absence of risk is not feasible.
2. Management goals described in the context of acceptable levels of risk.
3. Workable components of a fire safety system that can be adapted to any building.
4. An event logic tree expressing relationships between the different system components.
5. A method of calculation enabling the performance of a fire safety system to be quantified.
6. The use of probability to describe fire safety performance.

Using GSA Appendix D as a base, practitioners and others have made further developments. For instance, the National Fire Protection Association formed the committee on Systems Concepts for Fire Protection in Structures. In 1973, this committee published an event logic tree relating the components of building fire safety. In 1974, this document was revised and updated. Among its current projects the Committee is relating NFPA standards with the systems approach and developing system quantitication techniques.

A second example is the work at the Worcester Polytechnic Institute in Worcester, MA. A series of courses in system design for building fire safety, predicated upon the fundamentals of GSA Appendix D resulted in the evolution of network systems diagrams. The diagrams were originally developed to show the logic of the conceptual fire safety design process with regard to the application of event logic trees, such as those of GSA and NFPA. Later this diagramatic logic was modified to a form that could be mathematically evaluated.

The book being developed under this grant has four basic elements (Figure 1). Basic concepts of fire protection, systems theory in general and systems theory applying event logic trees and network diagrams to fire safety problems form element one -- the first three chapters.

Element two deals with tools of the systems approach: burning in a space, barriers, burning and barriers together, smoke and people. It covers nine chapters.

Element three is four chapters in length and deals with the application of the fundamentals of element one, coupled with the tools of element two to real world fire safety problems in the built environment.

Element four, the state-of-the-art, is a putting together of all the elements in summary form. Appendices on several subjects are also included.

In greater detail, the specific chapters in each element are:

Basic Concepts - Chapters 1,2 & 3

- The Evolution of Fire Protection
- Useful Concepts of Systems Approaches
- Concepts of Engineering a Fire Safety System

Tools - Chapters 4 - 12

- Describing the Fire Growth Hazard
- Modifying Fire Growth by Suppression
- Limit of Fire Growth Within a Compartment
- Predicting Fire Exposure
- Predicting Barrier Performance

Figure 1

ELEMENTS OF THE BOOK

BASIC CONCEPTS	3 Chapters
TOOLS	9 Chapters
Burning in a Space	
Barriers	
Burning & Barriers Together	
Smoke	
People	
APPLICATIONS	4 Chapters
STATE OF THE ART	1 Chapter
APPENDICES	

Limit of Fire at a Barrier

Determining the Limit of Flame Movement

Determining the Limit of Smoke Movement

Principles of People Protection

Applications - Chapters 13 - 16

Design for People Protection

Design for Property Protection - Compartmented Building

Design for Property Protection - Uncompartmented Building

Design for Operational Continuity Protection

State-Of-The-Art - Chapter 17

Appendices - A through D

Glossary

Analytical Techniques

Decision Trees

Annotated Bibliography

Throughout the book, application of event logic trees and network diagrams is obviously emphasized. It is the use of these tools, together with the curves originally developed for GSA Appendix D, which are so powerful.

For instance, among the examples in Chapter Two is an event logic tree which describes automatic suppression within a designated area (Figure 2). For this event to occur, three things must happen. The circle with a dot in the center signifies an "and" function. In other words, the sprinkler must be present AND water must discharge from the sprinkler head AND there must be sufficient water to suppress the fire. In turn, each of these events can be further broken down.

Figure 2: Graphic Logic Tree for Automatic Suppression

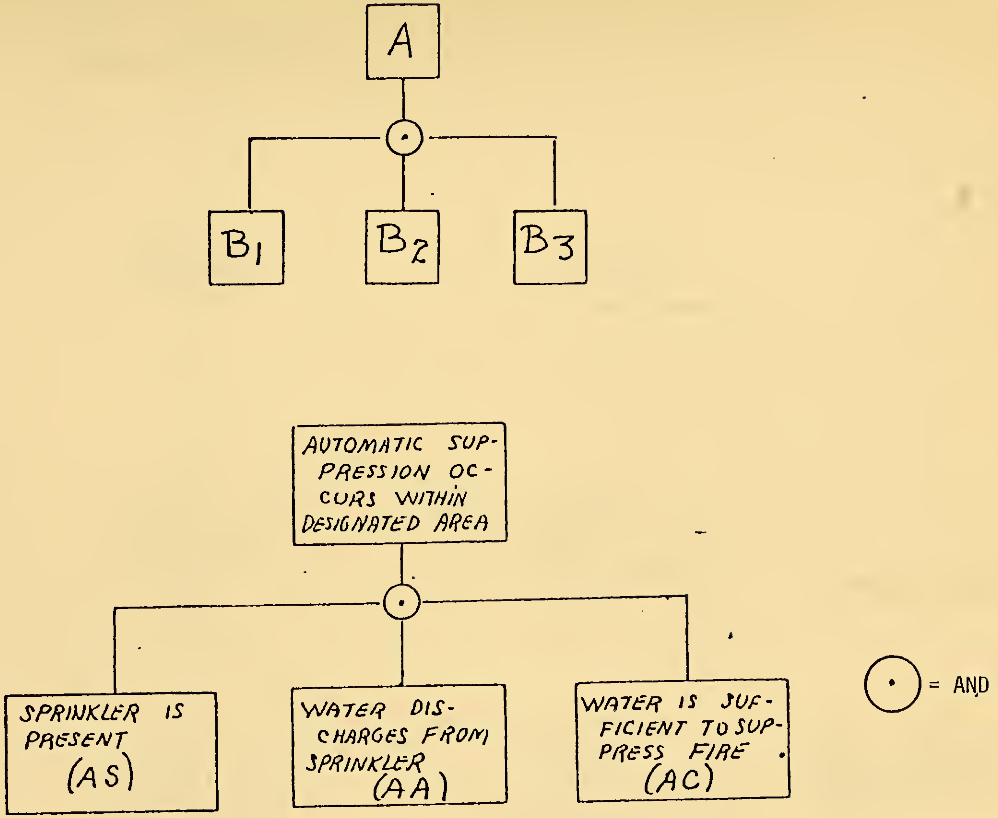
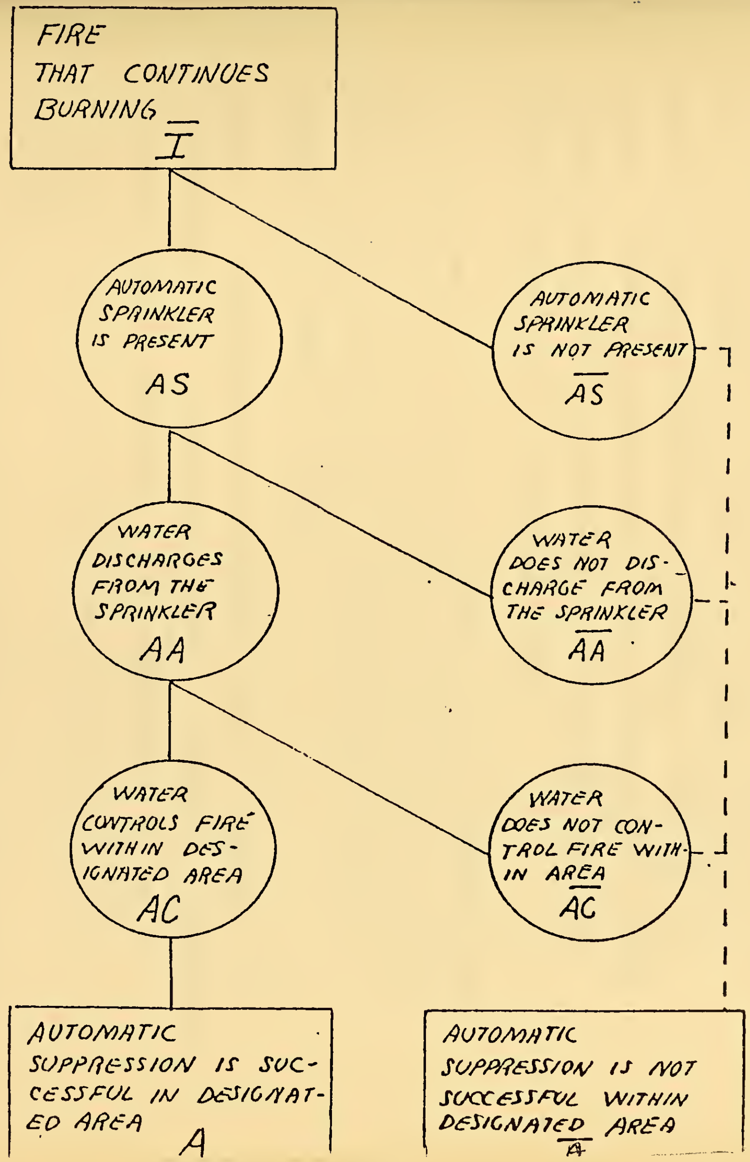

A
B1
B2
B3
AUTOMATIC SUPPRESSION OCCURS WITHIN DESIGNATED AREA
SPRINKLER IS PRESENT (AS)
WATER DISCHARGES FROM SPRINKLER (AA)
WATER IS SUFFICIENT TO SUPPRESS FIRE (AC)
= AND

Figure 3: Alternative Representation of Automatic Suppression


FIRE THAT CONTINUES BURNING $\overline{I}$
AUTOMATIC SPRINKLER IS PRESENT AS
AUTOMATIC SPRINKLER IS NOT PRESENT $\overline{AS}$
WATER DISCHARGES FROM THE SPRINKLER AA
WATER DOES NOT DISCHARGE FROM THE SPRINKLER $\overline{AA}$
WATER CONTROLS FIRE WITHIN DESIGNATED AREA AC
WATER DOES NOT CONTROL FIRE WITHIN AREA $\overline{AC}$
AUTOMATIC SUPPRESSION IS SUCCESSFUL IN DESIGNATED AREA A
AUTOMATIC SUPPRESSION IS NOT SUCCESSFUL WITHIN DESIGNATED AREA $\overline{A}$

Note: A bar (-) over the letter abbreviation signifies "does not"

Another example in Chapter Two describes the same phenomenon only by use of a network diagram. Given that a fire continues burning, automatic suppression will be successful only if all of the events "automatic sprinkler is present", "water discharges from the sprinkler" and "water controls the fire" within the designated area occur. Automatic suppression will not be successful if one or more of these elements do not occur, sprinkler not present, or water does not discharge, or water does not control. The events describing water discharge and control can be further divided (Figure 3) into additional networks which show the events that describe these components in even greater detail.

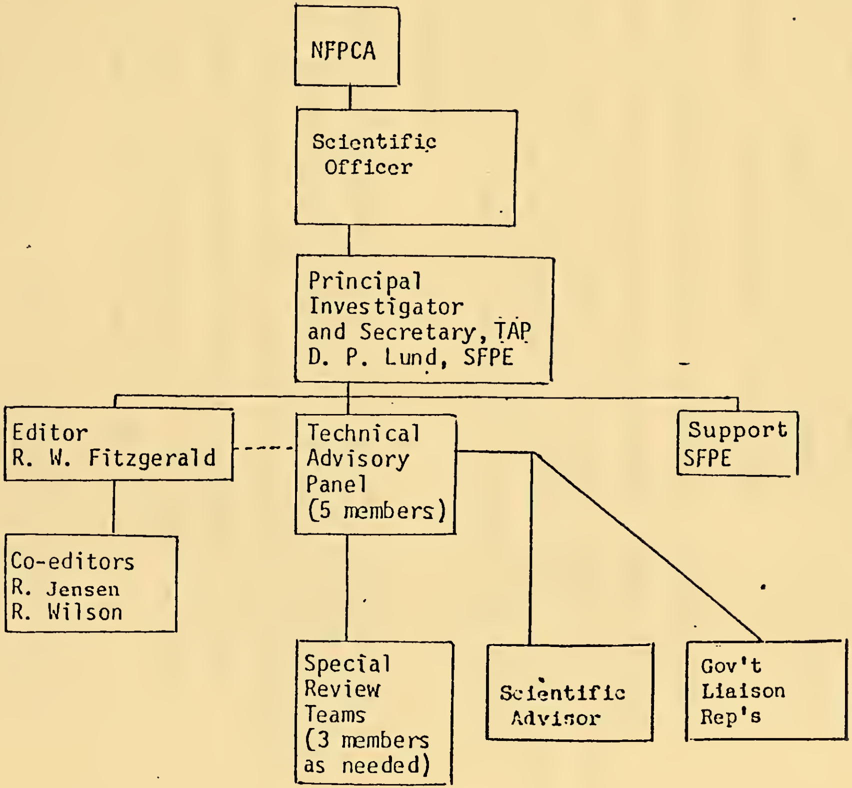
Such an exercise, employing either event logic trees, network diagrams or both, enables the fire safety analyst to examine in detail the specifics of the problems under consideration. Numbers can also be introduced as probabilities of success or failure.

Process: While the product of this grant, the book, is paramount, the process by which it is created is also important. The input of knowledgeable people, in addition to the editorial team doing the actual writing, is imperative. That contribution lends greater visibility and credibility to the project.

A project organizational chart is shown in Figure 4. The Scientific Officer for NFPCA is John Ferguson, Fire Protection Engineer. Principal Investigator and Secretary of the Technical Advisory Panel is D. Peter Lund, Executive Director, SFPE, who has overall responsibility for the project. The editorial team is composed of Editor Dr. Robert W. Fitzgerald, Associate Professor of Civil Engineering, Worcester Polytechnic Institute, and co-editors Rolf Jensen, President, Rolf Jensen and Associates, Inc., and Rexford Wilson, President, FIREPRO, Inc.

Figure 4:

Project Organizational Chart


NFPCA
Scientific Officer
Principal Investigator and Secretary, TAP D. P. Lund, SFPE
Editor R. W. Fitzgerald
Technical Advisory Panel (5 members)
Support SFPE
Co-editors R. Jensen R. Wilson
Special Review Teams (3 members as needed)
Scientific Advisor
Gov't Liaison Rep's

The technical advisory panel (TAP) provides technical evaluation of the evolving manuscript. The Chairman is Dr. William J. Christian, Underwriters Laboratories. Members of this panel are Dr. John L. Bryan, University of Maryland, Dr. John N. deRis, Factory Mutual Research Corporation, Building Commissioner Joseph F. Fitzgerald, City of Chicago and Professor Lars Lerup, University of California.

Scientific advisor to the project, editors and TAP specifically is Harold E. Nelson, Chief, Program for Design Concepts, Center for Fire Research, NBS. During the early 1970's, Mr. Nelson was Director of Accident and Fire Protection for the General Services Administration, and is credited with bringing modern systems concepts to fire protection. GSA Appendix D being the foundation.

Government Liaison Members to the TAP were also appointed bringing to bear the fire safety systems experience from the public sector. They are Thomas E. Goonan, Fire Safety Engineer, General Services Administration, Jonas L. Moorhart, Fire Protection Engineer, Department of H.E.W., Daniel F. Sheehan, Fire Protection Engineer, U.S. Coast Guard, and Thomas H. Seymour, Senior Project Manager, OSHA.

While the thrust of the project is to document the methodology developed in the United States so as to allevaite the fire problem in America, the problem of fire is a world-wide problem. Outstanding contributions to the fire problem have been made by individuals representing many nations. With that in mind, several leading fire protection professionals were invited to serve as corresponding members of the TAP.

They are: Dr. Arthur Edward Bamert, Brand-Verhutungs-Dienst fur Industrie and Gewerbe, Switzerland; Barry M. Lee, Technical Director, Fire Protection, Wormald International, Australia; Dr. Sven Erik Magnuson, Lund Institute of Technology, Sweden; John H. McGuire, Fire Research Section, NRC, Canada; Dr. P.H. Thomas, Fire Research Station, England and Professor D.J. Rasbash, Department of Fire Safety Engineering, University of Edinburgh, Scotland.

Also provided for but not employed during Phase IA of the project are Special Review Teams (SRT's). SRT's will be appointed as necessary to provide an in-depth analysis of particular aspects of the manuscript. As chapters one, two and three have developed, this SRT mechanism may be profitably employed to examine the basic systems descriptions in chapter two and to review the historical evolution of fire protection engineering and systems development contained in chapter one. Two or three experts in each of these fields will be recruited to do the job. The SRT concept is a further development of the earlier expressed philosophy to bring visibility and credibility to the book.

"WHICH FIRE INSPECTION PRACTICES ARE MOST IMPORTANT IN FIRE PREVENTION?"

John R. Hall, Jr.
Research Associate
The Urban Institute

Grant #APR76-19148

WHICH FIRE INSPECTION PRACTICES ARE MOST IMPORTANT IN FIRE PREVENTION?

by
John R. Hall, Jr.
Research Associate
Urban Institute

Five years ago, the National Commission of Fire Prevention and Control recommended that fire departments give more emphasis to fire prevention in general and to fire prevention code enforcement and fire safety in buildings in particular. Many fire departments wishing to respond to this recommendation have been frustrated by the lack of good research-based guidelines on the best way to design inspection programs. As a first step in providing such guidelines, the Urban Institute and the National Fire Protection Association have been conducting a study (funded by the National Fire Prevention and Control Administration and the National Science Foundation) of relationships between fire inspection program practices and lower rates of fires, fire losses, and fire casualties. The project's final report will be available in early 1979, and some preliminary conclusions can be cited here. Two cautionary points should be made in connection with these findings: First, the analysis has not yet been completed, and it is possible that the conclusions may be modified somewhat when all the results are in. Second, the project involved no experimentation with different inspection practices but only an examination of naturally occurring differences among eleven cities; therefore, any attribution of low fire rates and the like to certain inspection practices runs the risk that these practices are in fact correlated with other conditions or policies and that these other conditions or policies are the real reasons for the lower fire rates.

The first finding has to do with the nature of inspection impacts on fire rates and fire losses. In each of the eleven cities and in several other cities as well, building fires in inspectable properties were separated into four classes, according to the relative preventability of their causes of ignition. The classes were: relatively unpreventable (incendiary and natural-cause fires), preventable by motivation of safer behavior (e.g., careless-smoking fires), preventable by motivation of better maintenance (e.g., short-circuit fires), and preventable by direct hazard removal (e.g., fires due to trash too near a water heater). Interviews with inspectors and managers of inspected businesses tended to agree that inspections could have a large impact only on the last class of ignition,causes but these causes never accounted for more than 5-10% of all fires. It appeared, then, that the cities having more success in preventing ignitions probably were succeeding not because of greater thoroughness in removing hazards but rather because of greater success in motivating the managers of inspected properties (or because of programs other than fire inspection programs).

When the analysis turned to an examination of differences in inspection practices between high-fire-rate and low-fire-rate cities, the results were at least consistent with the finding that inspections succeed more through motivation than through direct hazard-removal. An extremely strong relationship was found between the cities' fire rates and their relative success in providing regular, annual inspections to all or nearly all inspectable properties. Those cities that missed substantial numbers of properties on annual inspections, either because the city was not aware the businesses were there or because there were too few inspectors to cover the city, had high fire rates; those cities that missed very few inspectable properties had low fire rates. The results also

suggested that it is much harder to have enough inspectors to go around if the fire department attempts to use full-time inspectors for all inspections, possibly because full-time inspectors constitute a visible expense that is politically easier to cut. That is, some use of suppression companies as inspectors appeared to be necessary to cover the city on a regular basis. The results also suggested that a block-by-block approach to inspections, backed up by some documentation (like checklists of blocks completed) for management control, is the best way to assure that all or nearly all inspectable properties will be reached. Computerized records can provide useful information in the field and reduce paperwork time for inspectors, but computerized lists of the properties to be inspected will tend to become obsolete in time as new businesses pop up in out-of-the-way locations, unless the block-by-block approach is used, too.

The importance of just getting around once a year to all the inspectable properties appears to be so great that it may overshadow current city-to-city differences in the quality of inspectors, the strictness of enforcement practices and the particular approach to motivation taken by the city. However, the analysis of the relative importance of these other factors still is in process, and no firm conclusions can be made at this time.

Regarding the impact of codes and inspections on fire casualties, there appear to be two distinct cases. The overwhelming majority of fire casualties occur in ones and twos in circumstances that fire inspections and current codes appear to be unlikely to prevent, given that the fire occurred. An analysis of casualties in two cities where the detailed circumstances were routinely written up showed that all but a few deaths and injuries involved one of the following relatively unpreventable situations: (1) The casualty occurred to the person whose careless actions started the fire, usually at the same time as the ignition. (2) The casualty occurred to someone else in the room or apartment unit of

origin, where casualties can easily occur even if all code provisions have been followed. (3) The casualty occurred to someone while he or she was trying to aid in rescue or extinguishment; these casualties are to a certain extent "voluntary."

On the other hand, casualties in fires where many people die appear to be highly preventable. An analysis of fires involving 10 or more deaths from 1969-1977 showed that most of those deaths were attributed to a relatively small set of deficiencies in a few types of occupancies. These deficiencies were as follows: (1) the lack of sprinklers, the lack of adequate fire separations (especially corridor partitions), and the use of wood wall panelling in nursing homes; (2) the presence of open stairways in hotels and apartment buildings; and (3) insufficient, blocked, or poorly marked exits, and overly combustible interior finish in restaurants and lounges. These deficiencies should be regarded as priority items in any program of controlling building features. Also, retrofitting of older buildings and stricter controls on smaller buildings may be necessary to achieve real success. All eight hotel fires indicating year of construction were over 40 years old; eight of twelve apartment fires indicating building height were in buildings of three stories or less.

"SPRINKLER TRADEOFFS"

Russell P. Fleming
National Automatic Sprinkler and Fire Control Association, Inc.

ABSTRACT

A grant has been received by the Council of American Building Officials to investigate the basis of current requirements and design alternatives for automatic fire sprinklers in the model building codes and assess their potential economic impact. The National Automatic Sprinkler and Fire Control Association will be working with CABO in the 12-month research program. The program will build upon the NAS and FCA 1977 publication, Architects' and Engineers' Guide to Automatic Sprinklers in Building Codes. That publication is the result of extensive research and organization of code provisions relating to automatic sprinklers. The section of the Guide relating to the 1975 edition of the Basic Building Code can be used as an example of the role of "Automatic Sprinklers in Building Codes". The research program will include four major elements: (1) the identification of model code requirements and design alternatives for automatic sprinklers; (2) an evaluation of the potential economic impact of including an automatic sprinkler system in building design, taking full advantage of construction economies permitted as "trade-offs" for sprinkler installation; (3) an investigation and compilation of the background, test data, and experience supporting all model code provisions relating to automatic sprinklers; and (4) an analysis of the adequacy of existing sprinkler requirements and design alternatives permitted with sprinkler system inclusion, with possible recommendations for deleting or adding specific sprinkler requirements and design alternatives as justified. The NAS and FCA research team will draw upon extensive in-house file resources representing two decades of experience in the model code field. Close cooperation is expected between team members and the building regulatory process, as well as with those organizations and testing laboratories involved in the development of test

data which led to the adoption of code provisions relating to sprinklers. The program will employ the services of Lothrop Associates, an architectural design firm, to accurately estimate the cost impact of sprinkler design alternatives, using specific building designs with and without sprinklers. It is expected that the final report will have a major impact on community leaders, local building and fire officials, and professional designers.

"A STUDY OF FIRE SAFETY EFFECTIVENESS STATEMENTS"

By

Jack Watts and James A. Milkie
Department of Fire Protection Engineering
University of Maryland
College Park, MD

USFA Contract #7-33563

ABSTRACT

The Federal Fire Prevention and Control Act of 1974 charged the Administrator of the newly formed National Fire Prevention and Control Administration to develop guidelines to formulate Fire Safety Effectiveness Statements. This presentation discusses the first two tasks of the project to develop these guidelines.

The first task is primarily concerned with the vital objective of setting a firm theoretical and practical foundation upon which the remainder of the project can be based. As a part of this task, the scope of the entire project is defined after tracing the development of the concept of the Fire Safety Effectiveness Statement from its origination by the National Commission on Fire Prevention and Control. Emphasis is then placed on determining the variables of building occupants, construction and environmental features which affect Life Safety, should a fire occur. The qualitative relationships of the selected variables are examined to determine the key variables. In this analysis, the key variables are defined as the variables which are independent and multi-functional.

In the second task, thirteen systematic methods for grading fire safety have been reviewed for this task. The models selected for review fall into three groups according to the basic techniques employed: deterministic, probabilistic and simulation. The three criteria for review and evaluation of the models are internal validity, external validity and utility.

Table 1 The Selected Variables Influencing Life Safety

	The Selected Variables	Descriptions of the Variables
	Variables Which Describe the Occupants	
1.	Physiological/Psychological Condition	Age, Sex, Mental and Physical Health, Mobility
2.	Sociological Orientation	Work, Social Gathering, Residence
3.	Previous Training, Experience	Drills, Evacuation Pre-plans, Previous experience with Fires
4.	Familiarity of the Building	Visitor vs. normal occupant
5.	Egress Leadership	"Fire Warden", Teachers in Schools
6.	Alertness	Asleep vs. awake, intoxicated
7.	Irrational Actions/Behavior	Panic, unpredictable, unreasonable reactions
8.	Occupant Load	Number of occupants in any given area
9.	Density in Corridors/Exitways	Predicted number of occupants per $ft.^2$ in exitway, during egress
10.	Ratio of Immobile to Mobile Occupants	Nurse/Patient ratio, etc.
	Variables Which Describe the Features of the Building	
11.	Height of Building	Height in feet and/or number of stories
12.	Construction Class of Building	Non-combustible vs. Combustible structural frame
13.	Fire Resistance of Structural Members	Rating in minutes or hours of all load-bearing members
14.	Compartmentation	Fire-resistant tenant separation, horizontal and vertical separations, rating of each in minutes or hours.
15.	Fire Resistance of Exitway Enclosure	Rating in minutes or hours of common corridors
16.	Fire Resistance of Vertical Shafts	Rating in minutes or hours of stairways, elevator shafts, pipe chases
17.	Fire Resistance of Separation of Hazardous Areas	Rating in minutes or hours around mechanical equipment rooms, paint storage or spraying rooms

The Selected Variables	Descriptions of the Variables
18. Protection of Openings in Fire Resistant Enclosures	Rating in minutes or hours of device, appropriate for enclosure rating
19. Heat Actuated Automatic Closing Devices	Fusible links
20. Exposure Protection	Distance to adjacent building, fire shutters
21. Exterior Fire Spread	Spandrels, draft deflectors, material type on building exterior at junction of fire resistant assembly and exterior wall
22. Windows	For: exterior fire attack and egress, ventilation of heat and smoke, and exterior fire spread
23. Electrical System	Potential ignition source: faulty wiring
24. Mechanical System	Potential ignition source: oil furnace backfire
25. Elevators	Operation during fire as aide to immobile occupants, otherwise as hazard
26. Centrally Located Watch Desk	Guard desk, nurse's station
27. Ignition Prevention Measures	Grounding/Bonding of electrical equipment, explosion-proof fixtures, no-smoking regulations

Variables Which Describe the Means of Egress

28. Exitway Dimensions	Exitway width, travel distance
29. Egress Capacity	Necessary width for evacuation of all occupants
30. Remoteness/Independence of Exitways	Multiple means, remote and not directly connected
31. Dead-end Exitways	Any path of egress along only possible route
32. Lighted Exitways	Provision of emergency lighting
33. Obvious/Identified Exitways	Directional and Exit Signs, where needed, to identify means of egress
34. Operation of Exitway Doors	Door swing, hardware, openable with maximum force of 50 pounds

The Selected Variables	Descriptions of the Variables
35. Vertical Exitway Design	Stair Riser/tread ratio, ramp slope
36. Heliport on Roof	Use of heliport for evacuation as back-up measure
37. Exterior Fire Escape	Not limited to traditional metal stairs, i.e. chutes, slides
38. Balconies	For exterior egress (similar to windows), also potential area of refuge
39. Rescue by Fire Department	Rescue of occupants via ladders or assistance to occupants via interior of building

Variables Which Describe the Means of Detection, Alarm and Extinguishment

40. Automatic Detection System	Detectors for detection and alarm, excludes detectors actuating suppression systems
41. Manual Alarm System	Pull stations, boxes inside building
42. Distinctive Audible Alarms	Unambiguous audible and/or visual alarms
43. Public Address System	To inform/alert occupants
44. Emergency Control Center	Center automatically carries out necessary functions at receipt of alarm to alert occupants, initiate fire and smoke contro
45. Automatic Notification of the Fire Department	Direct connection to central station or fire department
46. Automatic Extinguishing System	Sprinklers or other suppression systems - includes actuating devices, system hardware, adequate water/agent supply
47. Standpipe System	Standpipe system, water supply
48. Portable Fire Extinguishers	Proper type and spacing of extinguishers for hazard
49. Systems Maintenance	Systems are properly maintained
50. Suppression by Fire Department	Availability of local fire service to suppress fire
51. Suppression by In-House Fire Brigade	Availability of a trained, in-house fire brigade to perform first-aid firefighting tasks.

Variables Describing the Means of Smoke Control

The Selected Variables	Descriptions of the Variables
52. Structural Smoke Control	Any partition to effectively limit the spread of smoke, including (but not necessarily limited to) approved smoke partitions
53. Pressurization of Adjacent Compartment	"Dynamic Smoke Control" - Use fans to pressurize stairways, zones of floor
54. Manual HVAC Shutdown	Capability of prompt shutdown of air handling system by manual means
55. Separate Shaft for Exhaust	Exhaust shaft exhausts all stale air directly to outside at time of fire
56. Exitways Used as Return Air Plenum	Use of corridors as return air plenum, return air ducts for zone located in corridor
57. Automatic Shaft Vents	Vents at top of stairs, smoke detector actuated
58. Compartmented Stairway	Horizontal zoning of stairways by physical separations
59. Opening protection for Smoke Partitions	Smoke Dampers, Doors
60. Smoke Actuated Automatic Closing Devices	Smoke detectors, operate dampers, doors

Variables Which Describe the Properties of the Potential Fuel

61. Probability of Ignition	Inherent hazard of the material or process Frequency of incendiary fires
62. Energy Load	Fuel load, considering: pounds per square foot, surface to mass ratio, fuel configuration
63. Rate of Energy Release	Explosive, smoldering
64. Time Duration of the Fire	Predicted length of unchecked fire, in minutes
65. Toxicity of the Combustion Products	Lethal concentration, maximum temperature
66. Light Attenuation by the Combustion Products	Smoke Developement Number

Table 2 Functional Analysis of the Independent Variables

Key

X - Variable Contributes to function

? - Variable may contribute to function

FUNCTIONS

INDEPENDENT VARIABLES	Prevent Fire Ignition	Control Movement of Fire	Control Combustion Process	Manage Intrusions of Harmful Effects of Fire	Automatically Suppress Fire	Manually Suppress Fire	Cause Movement of Occupants	Defend in Place	Provide Movement Means for Occupants	Provide Rescue for Exposed Occupants
Physiological/Psychological Condition	X					?	X	?	X	
Sociological Orientation						?	X			
Occupant Load									X	
Height of Building				X		X		X	X	X
Fire Resistance of Structural Members		X				X			?	X
Compartmentation		X		?				X		?
Fire Resistance of Exitway Enclosure		X		?					X	?
Fire Resistance of Vertical Shafts		X	X	?						
Fire Resistance of Hazardous Area		X		?				X		
Exposure Protection	X									
Electrical System	X									
Mechanical System	X									
Ignition Prevention Measures	X									
Exitway Dimensions									X	X
Remoteness/Independence of Exitways									X	X
Lighted Exitways									X	
Obvious/Identified Exitways									X	
Operation of Exitway Doors									X	
Vertical Exitway Design									X	
Rescue by Fire Department										X
Automatic Detection System		X		X			X		?	
Automatic Extinguishing System		X	X		X		X	X	X	X
System Maintenance	X	X	X	X	X	X	X	X	X	X
Suppression by Fire Department		X	X	X		X		X		X
Suppression by In-House Fire Brigade		X	X	X		X		X	X	X
Pressurization of Adjacent Compartment		?	?	X				X	X	X
Separate Shaft for Exhaust			?	?				?	?	?
Exitways Used as Return Air Plenum									X	
Probability of Ignition	X									
Energy Load		X	X		X	X	X			
Rate of Energy Release		X	X		X	X	X			
Toxicity of the Combustion Products				X			X		X	X
Light Attenuation by the Combustion Products				X			X		X	X
Contruction Class of Building		X								

Description of the Functions Utilized in the Functional Analysis*

Prevent Fire Ignition: "prevent initiation of destructive and uncontrolled burning"

Control Movement of Fire: "obtain this objective through the provision and activation (where necessary) of "building protection features and built-in equipment"

Control Combustion Process: "control the inherent fire behavior"

Manage Intrusions of Harmful Effects of Fire: "control fire impacts into the place containing the exposed"

Automatically Suppress Fire: "perform actions of a fire process in order to limit the growth of or to extinguish the fire", "without need of human action"

Manually Suppress Fire: same as Automatically Suppress Fire, except with the need of human action.

Cause Movement of Occupants: "means to initiate movement of the exposed to and along a safe path"

Defend in Place: "defend the place occupied by the exposed"

Provide Movement Means for Occupants: "provide the facilities necessary for a safe path through which the exposed can be relocated"

Provide Rescue for Exposed Occupants: provide the facilities and assistance necessary for a path through which the exposed can be relocated.

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*Utilizing definitions of the NFPA Systems Concepts Committee (sic)

TABLE 3. THE KEY LIFE SAFETY VARIABLES

(A KEY LIFE SAFETY VARIABLE HAS BEEN DEFINED AS AN INDEPENDENT AND MULTI-FUNCTIONAL VARIABLE)

HEIGHT OF BUILDING
FIRE RESISTANCE OF STRUCTURAL MEMBERS
COMPARTMENTATION
FIRE RESISTANCE OF EXITWAY ENCLOSURES
FIRE RESISTANCE OF VERTICAL SHAFTS
FIRE RESISTANCE OF HAZARDOUS AREA SEPARATIONS
EXITWAY DIMENSIONS
REMOTENESS/INDEPENDENCE OF EXITWAYS
AUTOMATIC DETECTION SYSTEM
AUTOMATIC EXTINGUISHING SYSTEM
PRESSURIZATION OF ADJACENT COMPARTMENT
PHYSIOLOGICAL/PSYCHOLOGICAL CONDITION OF OCCUPANTS
ENERGY LOAD
RATE OF ENERGY RELEASE
TOXICITY OF THE COMBUSTION PRODUCTS
LIGHT ATTENUATION BY THE COMBUSTION PRODUCTS
SUPPRESSION BY IN-HOUSE FIRE BRIGADE
SUPPRESSION BY FIRE DEPARTMENT
SYSTEM MAINTENANCE

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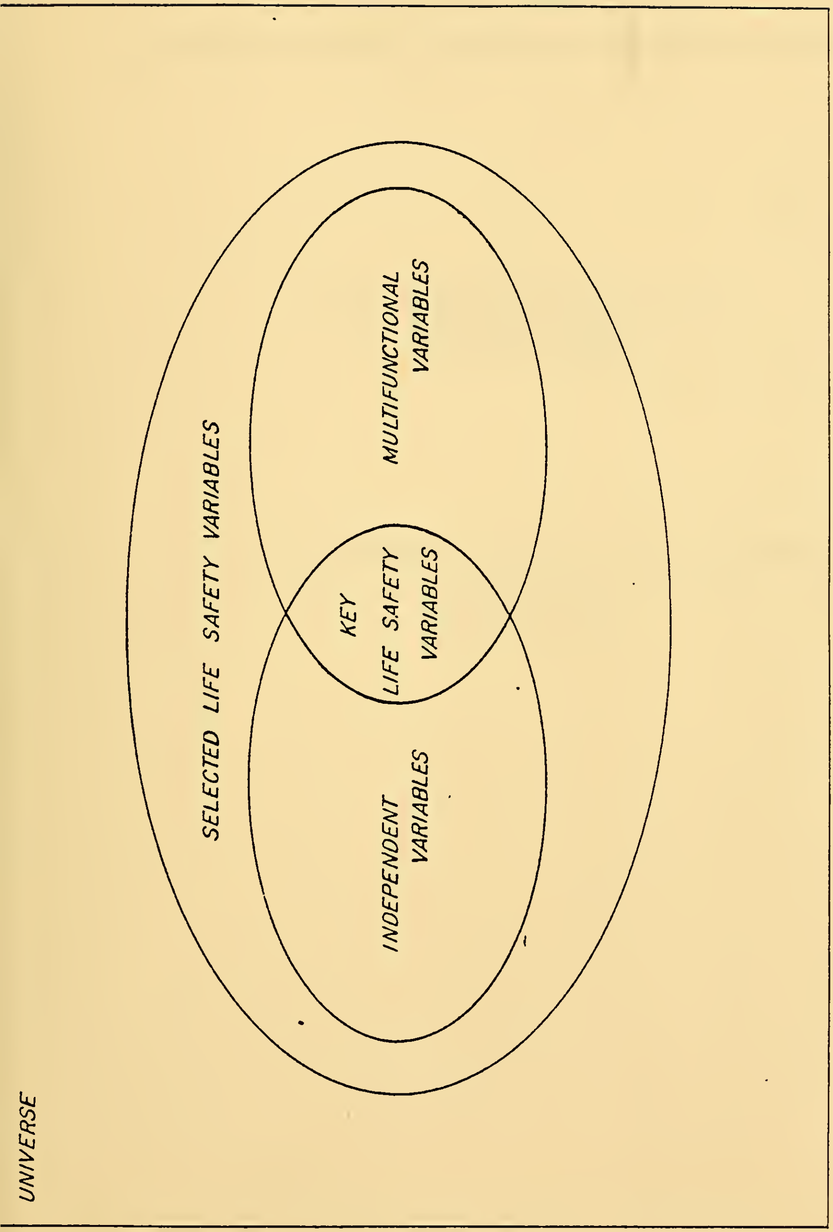
UNIVERSE
SELECTED LIFE SAFETY VARIABLES
MULTIFUNCTIONAL VARIABLES
KEY LIFE SAFETY VARIABLES
INDEPENDENT VARIABLES

THE BUILDING FIRESAFETY MODEL:

A QUANTITATIVE APPROACH TO DETERMINING FIRESAFETY EFFECTIVENESS

By

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U.S. Department of Housing and Urban Development

Contract #H-2316

New materials, construction methods, and contents are rapidly changing the nature and magnitude of the fire problem in the United States. These changes often provide a situation that is not covered explicitly in existing codes or that requires amendments to allow their installation. In some cases, these changes in construction or materials provide a safer environment. It is desirable to take advantage of these changes and to encourage similar advances within the framework of the codes. An important step in that direction is the development of rigorous procedures for objectively evaluating the equivalency of such changes to the accepted standards.

A systematic procedure for measuring the hazards of building fires has been developed as part of a project being funded by the Department of Housing and Urban Development. This procedure, called the "Building Firesafety Model," incorporates data derived from actual fire tests to describe the rate of fire growth, the likelihood of entrapment, and estimates of structural damage.

It is expected that this tool will assist government officials, architects and engineers in evaluating the design (or rehabilitation) of buildings with regard to the level of firesafety. Such a tool could potentially be used to evaluate the comparative levels of firesafety implied by compliance with codes and to identify voids in fire test data. In addition, the model can be used for evaluating the allocation of fire service and prefire tactical planning.

Building Firesafety Model

The Building Firesafety Model is a computer simulation that is based on a state transition formulation of fire behavior. The model describes the temporal and spatial characteristics of fire development and the associated combustion products. The states of the Building Firesafety Model correspond to critical stages in fire development and are termed fire "realms." Starting with a pre-burning condition, the realms describe the progressive stages of fire growth within the room of origin and the extension throughout the dwelling. Realms are defined by several measurable criteria such as flame height, heat release rate and upper room air temperature. Information about the severity of the fire, the rate that combustion products are generated, and the opportunities for suppression are considered when defining the realms.

Figure 1 represents currently used definitions for each realm. Higher order realms are used to represent significant fire growth both in severity and spatially. As indicated by the realm definitions, extension of the fire is often considered at least as important as the fire development within the room of origin. The means of reaching a realm are no longer considered once it is reached. Fire development does not necessarily involve passing through all consecutive realms since transitions can represent both fire recession and growth. Furthermore, some rapidly growing fires such as explosions can in effect pass

Figure 1

Realm Definitions for Single-Family Dwellings*

REALM 1: Preburning. Situations prior to ignition and following termination of a fire are represented by this realm.

REALM 2: Sustained Burning. There is sustained burning of the fuel which includes smoldering.

REALM 3: Vigorous Burning. The heat release rate exceeds 2kW. It is expected that the flame height may be approximately 25cm and that the upper room air temperature has increased by 15°C above ambient temperature.

REALM 4: Interactive Burning. The upper room air temperature exceeds 150°C. It is expected that the flame height may be approximately 120cm and that the heat release rate may exceed 50kW.

REALM 5: Remote Burning. The upper room air temperature exceeds 500°C. It is expected that the external heat flux returning to the fuel surface exceeds $5kW/m^2$. This realm also includes secondary ignitions beyond the room of fire origin with the change in upper room air temperature in this area less than 15°C.

REALM 6: Room Involvement. There is full room involvement or an increase in upper room air temperature greater than 15°C beyond the room of origin.

REALM 7: Flame Spread. There is involvement beyond the room of origin with the upper room air temperature in this area exceeding 150°C.

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*These definitions are the result of discussions involving Dave Russell and Robert Thompson of NFPA, John deRis of Factory Mutual, and Rexford Wilson of Firepro.

through several realms so quickly that it is inappropriate to isolate these intermediate stages of fire behavior.

Two types of statistical distributions are required to describe the transition of fire from one realm to another as illustrated in Figure 2. A discrete distribution indicates the conditional probability of transition from a particular realm to each of the other realms. A continuous distribution indicates the variation in the time a realm exists. Since the nature of the transition and time in a realm are usually interdependent, the characteristics of the temporal distributions are provided for each possible transition.

The characteristics of these statistical distributions can be based entirely on fire test data. Data from tests involving single items and full scale tests were analyzed to determine the transition descriptors illustrated in Table 1 for a smoldering couch fire in a standard size living room. For example, from Realm 3, there is a 75% chance of growth to Realm 4 and a 25% chance of recession to Realm 2. Also based on these data, normal and uniform distributions were selected to describe the temporal transitions between Realms 3 and 4, and between Realms 3 and 2, respectively. The transition descriptors are based on limited data from a variety of sources (Appendix A). While the process for obtaining the descriptors is well established, the values may change as more data become available.

Step functions are used to model the combined hazards due to the accumulation of one or more of the combustion products. The hazards created by the accumulation of the combustion products

Figure 2

Realm Transition Descriptors

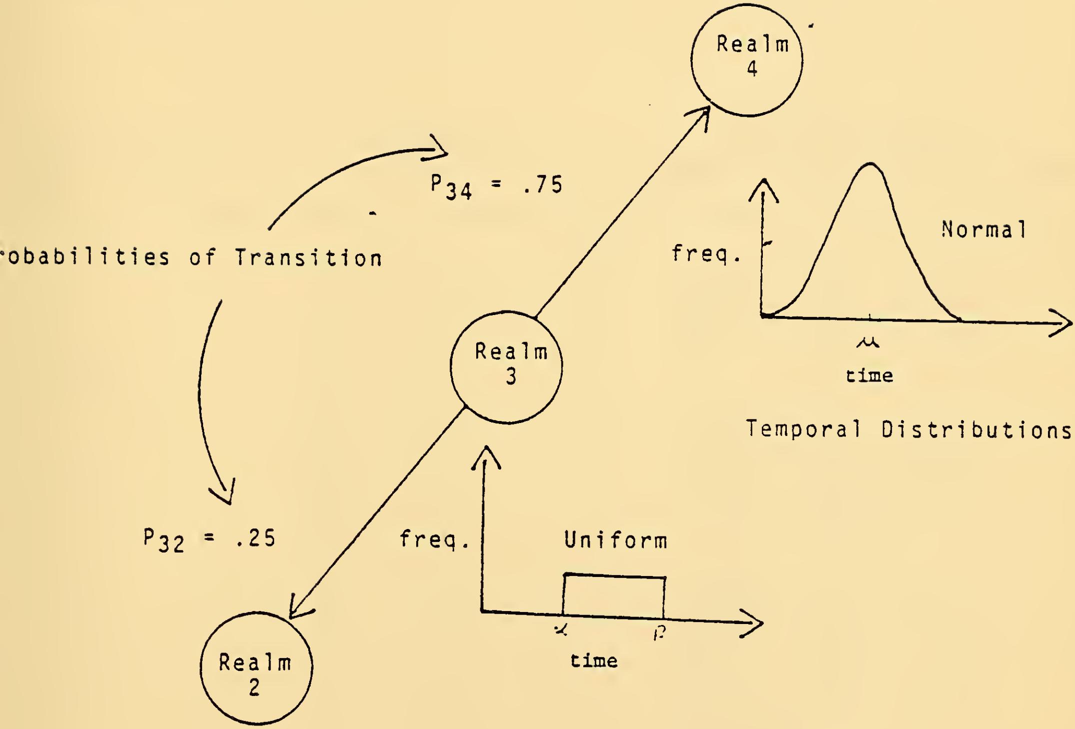


Table 1

Transition Descriptors*

Fire Type: Smoldering Couch Fire with Cotton Cushions

Dwelling: Single Family

Room of Origin: Living Room

Realm Transitions		Transition Probabilities	Temporal Distributions		
FROM	TO		Type	Parameter values (min.)	
2	1	.33	Uniform	$\alpha = 2$	$\beta = 5$
2	3	.67	Beta	$\mu = 1.95$	$\sigma = .71$
2	6	-			
3	2	.25	Uniform	$\alpha = 1$	$\beta = 2$
3	4	.75	Normal	$\mu = 7.58$	$\sigma = 3.32$
3	6	-			
4	3	.25	Uniform	$\alpha = 1.5$	$\beta = 9$
4	5	.75	Beta	$\mu = 204$	$\sigma = 1.65$
5	4	.08	Uniform	$\alpha = 0.6$	$\beta = 6.0$
4	6	.76	Log-normal	$\mu = 5.18$	$\sigma = 4.18$
5	7	.16	Log-normal	$\mu = 1.48$	$\sigma = 2.94$
6	7	1.00	Log-normal	$\mu = 1.48$	$\sigma = 2.94$

KEY

μ = mean
σ = standard deviation
α = lower bound
β = upper bound

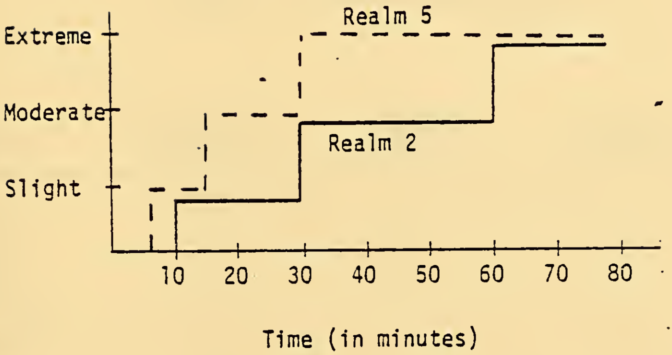
are described as causing either slight, moderate or extreme stress. The formulation of stress levels reflects the uncertainty regarding the effects of the combustion products and the importance of the perceived as well as the actual hazards. A step function describing the time for the progression from one level to the next higher stress level depends on the type of material burning during each realm. Separate functions are used to describe the stress variation in different locations and the effect of features that influence the spread of the combustion products. Figure 3 illustrates a few step functions for two rooms in a typical single family dwelling. This figure indicates that the combustion products will represent an extreme stress in the bedroom after 60 minutes even though the fire has not grown beyond Realm 2.

A measure of escape potential is used to describe one effect of the combustion products. For this project, escape potential is defined in terms of the routes available from any room to a location of safety. A tunnel, another fire compartment, or the outdoors can serve as a location of safety depending on the type of dwelling and mobility of the occupants. This technique is used to describe the susceptibility of routes to blockage by fire. Once the stress level reaches or exceeds some predetermined level, all escape routes through or from this location are eliminated. This level may be based on information describing when the level of combustion products presents an untenable condition or when the occupants may perceive a room to be impassable. Table 2 illustrates the relative effects of blocking either the kitchen or hallway in a particular single-family dwelling design. As might be expected, the consequences

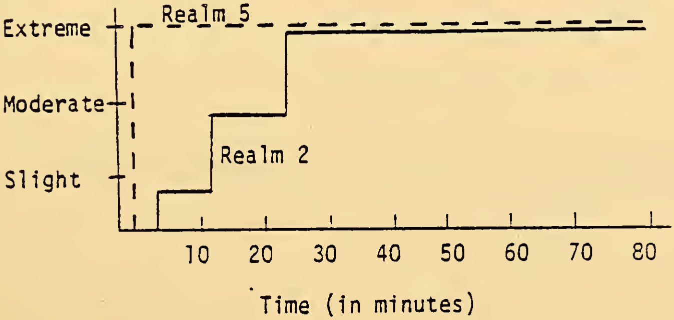
Figure 3

Stress Level Step Functions

- Single Family Dwelling
- Fire Originating in Living Room
- Smoldering Couch Fire



Step Functions For A Bedroom



Step Functions For Living Room

Table 2

Effect of Blocked Rooms on the Number of Escape Routes in a Typical Single Family Dwelling

Number of Directed Escape Routes

Location	All Rooms Passable	Kitchen Blocked	Hallway Blocked
Kitchen	3	x	2
Hallway	5	4	x
Living Room	3	2	2
Bathroom	1	1	0
Bedroom 1	2	2	1
Bedroom 2	2	2	1
TOTAL	16	11	6

NOTE: "x" denotes a room that is considered to be impassable.

of a fire in a central location such as the hallway will adversely affect the number of escape routes more drastically than a fire in a remote location.

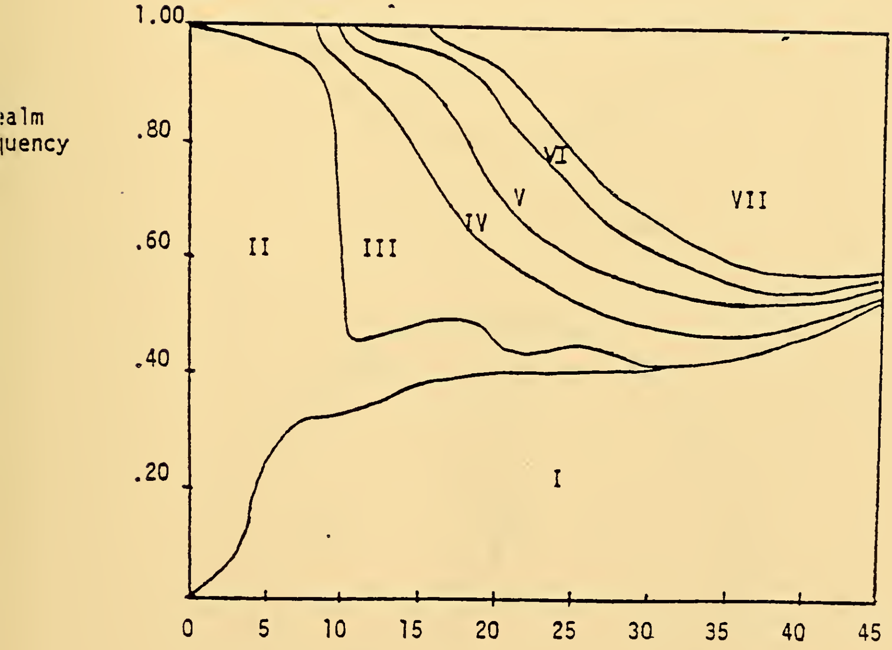
Quantitative Measures of Firesafety

The model provides a tool for assessing the expected characteristics of fire development. Figure 4 illustrates the results of 500 simulated fires based on the transition descriptors in Table 1. This figure indicates that at approximately 45 minutes, half the fires will have terminated. Figure 5 focuses attention on the expected status of the fire after 5 or 15 minutes. Based on the transition descriptors in Table 1, approximately 70% of the fires are still in the incipient stage (Realm 2) after 5 minutes and the remaining 25% will have terminated (Realm 1). However, after 15 minutes, the situation is much more complex with significant percentages of fires being in Realms 3, 4, 5, and 6.

Figure 6 illustrates the use of several measures for summarizing hazards in a single family dwelling. These measures provide quantitative information for the subjective evaluation of the fire hazards regarding escape potential, or conversely, entrapment. Furthermore, it may be possible to estimate the expected dollar loss due to flame because realms represent spatial involvement as well as fire strength.

Figure 4

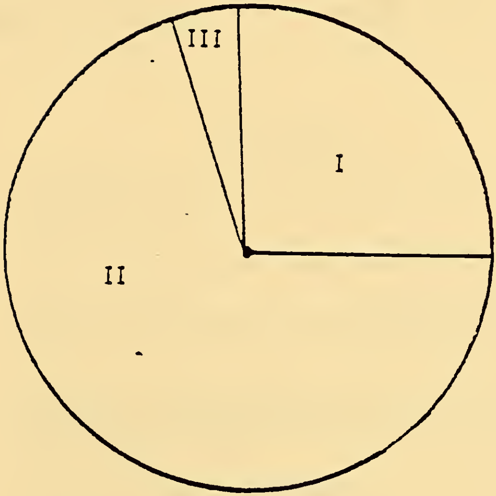
Simulated Fire Development*



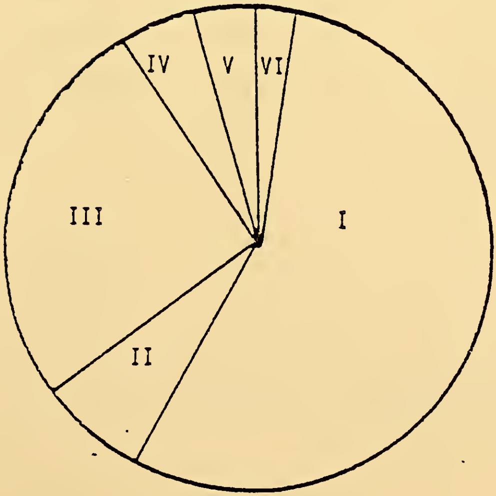
*Results are based on the transition descriptors in Table 1.

Figure 5

Fire Hazard at 5 Minutes



Fire Hazard at 15 Minutes



Realm Status Diagram

Figure 6

Comparison of Alternative Intervention Methods

For a Single-Family Dwelling

Fire Type: Smoldering Couch Fire   Room of Origin: Living Room

Measure		Description
A	-	Percentage of total fire duration that at least two directed escape routes are available.
B	-	Time when entrapment occurs with a probability of (0.33).
C	-	Average time before fires grow beyond an occupant's suppression capability. (Time to reach Realm 4.)
D	-	Percentage of fires that have not grown beyond an occupant's suppression capability in 10 min. (Growth beyond Realm 3.)
E	-	Average structural fire damage.

Design Description	A	B	C	D	E
Floor Plan 1 ($27,360)	44.8%	21 min.	17.1 min.	96.0%	$16,944
Fire Department Arrival*	81.6%	∞	13.1 min.	97.2%	$ 2,435
Room of Origin Suppression**	48.2%	20 min.	16.3 min.	95.4%	$14,832
Sprinkler System***	76.3%	∞	14.3 min.	96.6%	$ 3,441

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* 9.5 min. from ignition.

** 10 min. in Realm 4.

*** Activates in Living Room and Bedroom 1 after 2.5 min. at a "slight" stress level.

Figure 6 also illustrates the capability of the Building Firesafety Model to describe changes in the fire environment. The simulation of a fire can be interrupted to alter the pattern of fire growth and the spread of the combustion products. The following conditions can be used to identify when a change is to take place:

1) a specified time after ignition,
2) a specified time in a certain realm, and
3) a specified time at a certain stress level in any location

The change is then described in terms of new values for the realm transition descriptors and stress level step functions. For instance, changes could represent the collapse of a wall, the breaking of a window, the closing of a fire door, and the effect of different suppression systems.

Based on available data, examples of each of these simulation interrupts are illustrated. The arrival of the fire department, for example, is represented as a specified time after ignition. This time includes the delays in detection, notification, dispatch, response, and setup. The actuation of a sprinkler system is represented by a specified time at a certain stress level. The values presented in Figure 6 depend upon the accuracy of the times when the changes take place and the description of the change. Since there is very little information in the proper form available at this time, the results presented in this figure are only for illustrating the capability of the model and not for describing the effectiveness of the actual alternative intervention methods.

Validation Based on Actual Fire Experience

It is possible to use data from fire tests and actual experience to validate the model. However, there are difficulties with both types of comparisons. Accelerants are often used in the tests which usually causes the fire to grow faster than it normally would. Furthermore, most of the available data has been used for calibrating the model, and therefore, cannot be used for validation. Data describing fire experience do not identify when and why each fire terminated. This information is essential for rigorous validation.

Nevertheless, to illustrate how national fire experience data might be used, a weighted average of results for two different simulated situations is compared to NFIRS data. The situations represent the start of fire department suppression at 11.6 and 12.3 minutes after ignition. Figure 7 illustrates the expected extent of maximum flame spread for 500 fires. It is expected that better results are possible using a more extensive distribution of times describing the start of fire department suppression, an accurate description of the effectiveness of its suppression efforts, and a more complete representation of the expected fire types.

Procedure for Code Evaluation

To assess the overall safety of a particular building design, it is necessary to simulate various fire situations for the range of occupancy uses, interior finishes, furnishings, and

Figure 7

Initial Comparison of NFIRS Data and the Simulated Results

Maximum Limit of Fire Extent	Actual Flame Damage	Simulated Flame Damage*
Object of Origin	188	149
Part of Room of Origin	154	138
Room of Origin	27	86
Beyond Room of Origin	131	127

*weighted average

72 percent fire department arrival in 11.6 minutes.

28 percent fire department arrival in 12.3 minutes.

environmental conditions. The values for a collection of quantitative measures can then be used to reach an assessment of the safety of the particular building design as illustrated in Figure 8. The values for these measures serve as a hazard profile that can be compared to corresponding values for other designs that have been approved by the appropriate governmental agencies as a basis for judging the acceptability of the building design.

Potential Uses of the Building Firesafety Model

The Building Firesafety Model is an efficient tool for systematically evaluating alternative building designs and suppression mechanisms. Available data was used to demonstrate the following applications of the model:

- Analysis of alternative single-family dwelling floor plans.
- Benefits of a fire door in a high-rise structure.
- Study of smoke control procedures in care-type facilities.
- Analysis of stove hoods in mobile homes.
- Analysis of room size and fuel loading.
- Escape potential in the Beverly Hills Supper Club.
- Firesafety standards for products and barriers.

Figure 8

Evaluation of Firesafety Objectives

	Building Environment Analysis					
Firesafety Measures	Fire Situation: 1		2		3	
	Yes	No	Yes	No	Yes	No
1. Is the time in the initial stage of fire growth greater than I?						
2. Is the probability of growth in the first few stages less than P?						
3. Does it take longer than T minutes before entrapment occurs?						
4. During the first S minutes, are fires within an occupant's suppression capability?						
5. Is the expected structural damage less than x percent of its value?						

The model is structured around the type of data that are readily available from single item and full scale fire tests. Because of the separability of realms, the state transition formulation enables the integration of data from many sources. Data from different tests can either be combined or interchanged depending on the fire type and building design. Even data from tests that are prematurely terminated or that terminated on their own are useful. In this respect, the model serves as a framework for utilizing all fire test data without regard to the expectations for growth. Since the realm definitions describe the significant stages of energy release, the realms themselves serve as a useful way of summarizing the results of fire tests and provide guidelines for the proper instrumentation of a burn test. The resolution of the realms in describing the early stages of fire growth aids in making the fire test data useful to researchers looking at different problems. Furthermore, the model can be used to prioritize the need for certain fire tests. Sensitivity analysis will indicate the expected benefit of additional data to improve the level of confidence in the simulated results.

As part of an analysis of code equivalency, the model provides the mechanism for determining comparative levels of firesafety. In addition to describing the impact of fuel loading, ventilation, and room size, for example, the model also provides information that can be used to evaluate the benefits of early detection devices. Thus, the model can be used to describe the critical and redundant aspects of fire and building codes as

well as to describe the comparative benefits of alternative automatic protection equipment and structural features for limiting losses due to fire.

Of prime importance for fully realizing the benefits of the Building Firesafety Model is information on the spread of the combustion products. Since it is these fire products that cause entrapment and the actuation of the suppression and detection systems, the accurate modeling of the spread of the combustion products as a fire develops is crucial to the meaningfulness of the simulated results. At this time, however, little information is available for obtaining statistical confidence in the modeling of both the perceived and actual hazards of the combustion products.

It will also be necessary to specify in a formal manner the measures that will be used to describe firesafety. Building designs that have been approved in accordance with the provisions of a code should be used as benchmarks to describe the historical levels of firesafety. As distinguished from scenarios based on fire experience, it is necessary to develop a set of building environments and fire types that could be used for code evaluation. Decision rules based on derived measures of firesafety can then be readily used to assess the overall firesafety of the structure.

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Appendix A

TRANSITION DESCRIPTORS

The transition descriptors are based on a subjective evaluation of fire test data from numerous sources and of actual response observation.

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"SUPPRESSION SYSTEMS FOR RESIDENCES:
USER NEEDS AND POTENTIAL IMPACT"

By

Rolf Jensen
Rolf Jensen & Associates, Inc.

Contract USFA #635587

SUPPRESSION SYSTEMS FOR RESIDENCES:
USER NEEDS AND POTENTIAL IMAPCT

Rolf Jensen
Rolf Jensen & Associates, Inc.

ABSTRACT

The purpose of the study was to establish the extent to which automatic suppression systems may reduce the National Residential Fire Loss. It included identification of user needs, a determination of how suppression systems can be made most cost effective, how various organizations impact on the use of systems, and how greater use of suppression systems can be encouraged in residences.

The study involved surveys of owners and occupants of residences, and of organizations affected by the use of residential sprinkler systems. Data was analyzed using Decision Trees and Operations Research methods. The report describes means whereby less costly, more efficient residential sprinkler systems may be developed and an estimate of the potential impact that such systems may have on fire losses in residences.

"SUPPRESSION SYSTEMS FOR RESIDENCES - USER NEEDS AND POTENTIAL IMPACT"

By

Rolf Jensen

Last year, Rolf Jensen & Associates, Inc., along with Schirmer Engineering Corporation, completed a study of the existing automatic residential suppression system technology under contract to the National Fire Prevention and Control Administration (sic).

The ability of an adequate suppression system to cope with extinguishing a residential fire was obvious. The problem was to identify what was an adequate system and how we could get adequate systems into the nation's homes.

Fire record data and fire research data were studied to establish a residential fire scenario as a basis for selecting candidate suppression systems likely to be effective in fire extinguishment and lacking undesirable side effects (high cost, toxic, injury to residents, property damage, etc.).

Candidate systems using the following agents were evaluated:

- Carbon dioxide
- Halon 1301

- High expansion foam
- Multipurpose dry chemical
- Water

As a result of this study, agent/systems other than water were excluded from practical use by a combination of factors including:

- Cost
- Agent toxicity
- Agent-induced damage
- Practicality/agent leakage
- Aesthetics
- Maintenance
- False activation

A suppression system using water as the agent and similar to available automatic sprinkler systems (NFPA 13 or 13-D) was selected as the most likely candidate suppression system for use in residences.

Next, a series of telephone interviews was conducted to evaluate acceptability of the candidate systems. The sampling was evenly divided over the United States. Interviews were conducted with the owners of single-family residences, tenants in multiple family residences, and either owner or tenants living in rural single-family residences; a total of 1,000. The questions asked were varied depending upon the group and responses of the persons interviewed. This allowed a certain flexibility to explore different concepts which could not have been done had a formal list of questions been used.

Users interviewed showed a general lack of awareness or concern for the residential fire problem.

Approximately 50 per cent indicated that they would accept a residential suppression system. Fifty per cent would not accept a system; 10 per cent rejecting systems because of appearance, 10 per cent because of fear of accidental discharge, and 30 per cent because of the lack of a perceived fire threat.

Cost was a major factor in systems acceptance; 20 per cent said they would be willing to pay for a system. Nine per cent will pay up to $.20 per square foot; 7 per cent will pay up to $.40 per square foot; and 4 per cent will pay up to $.75 per square foot; 30 per cent would accept a system at no net cost.

Seventy per cent favored a requirement for systems in new residences if their property taxes would decrease.

Routine maintenance of an automatic suppression system will be acceptable to 85 per cent of those who accept a system.

The false system actuation tolerance expressed by those interviewed was approximately 90 per cent.

Personal interviews were conducted with representatives of private organizations to determine their reactions to the use of automatic residential fire suppression systems. No attempt was made to achieve a statistically valid sample, the plan being primarily to establish the views and opinions of those contacted. The organizations contacted were:

- Real estate agents
- Financial institutions
- Fire insurance industry
- Residential builders/developers
- System designers and installers
- Piping contractors
- Trade unions
- Manufacturers of automatic suppression system equipment
- Architects/engineers

From these interviews, many factors which influence the cost, benefits or practicality of installation were idenfified:

- per unit cost of land
    - Greater density of land use
    - Lesser lot line separations permitted
- per unit front foot cost with lower costs for
    - Streets
    - Sewers
    - Utilities
    - Sidewalks
- per unit services cost
    - Police
    - Fire
    - Schools

Benefits includes:

- Increased value of residence
- Lower mortgage interest rate
- Homeowners insurance premium reduction (fire only)
- Systems available -- new housing
- New residential system industry

  - Manufacturing
  - Distribution
  - Installation

- Insurance premium
- Real estate tax
- Federal income tax (increase)
- Mortgate interest rate (decrease)

Next we talked to local government approval agencies. Specifically, we talked to:

- Water utilities
- Health departments
- Fire departments
- Building departments

We found that they would:

- Require meters
- Require backflow prevention
- Require plans by contractor/engineer
- Discourage owner installed system
- Discourage direct alarms to fire department

Following this, we did a cost evaluation of several levels of sprinkler systems, including a Level I, or NFPA 13-D, system; a Level II system, which was essentially a 13-D system extended to cover all areas of the house and with a 30-minute water supply; and a Level III system which encompassed feasible improvements in installation technology. Each of these was evaluated in a one-story, two-story, and split-level 2,000 square

foot single-family residence, and for a 600 square foot multifamily apartment.

For a level I system, these study examples yielded costs varying from $.65 to $1.10 per square foot for contractor installation in single-family homes, and of $.35 per square foot owner installed in single-family homes. For multifamily housing, contractor installed, and assuming that the system would be an add-on to an existing standpipe system or to the domestic water system, the costs were between $.45 and $.55 per square foot.

In terms of total cost and using a 2,000 square foot single-family residence being built in a new subdivision, the following is possible: the installed system cost is $1190; it is feasible that the initial land cost can be decreased by $500 for a smaller lot, and $600 by less street frontage from negotiations with planners and developers. This produces a net installed cost under these circumstances of $90. Potential owner benefits in subsequent years add up to $81 per year in the categories shown. Note that the Federal income tax is shown as a negative benefit since we assumed that the homeowner would have less mortgage interest and property tax to "write off" when he files his tax return. Let me emphasize that it is not our purpose to say that these are precise numbers, but simply to show that there are some feasible considerations that may make the system installation attractive on a cost/benefit basis.

Using the developed data, the residential loss prevention potential of the candidate systems was evaluated by use of a logic tree method.

The logic tree approach (NFPA Decision Tree) permits a quantitative evaluation of the effect of an automatic residential suppression system on the National Residential Fire Loss by constructing graphical probability statements at input levels and using these to compute resultant probabilities at intermediate and output levels of the logic tree. It is recognized that the accuracy of this approach is limited by the accuracy of available input data. Regardless, the approach enables a reasonable approximation of:

- o The relative ability of each type of automatic suppression system to prevent residential fire-related losses. Systems can be ordered as to loss prevention effectiveness.
- o The reduction in the National Residential Fire Loss caused by automatic residential suppression systems (or any other fire control or prevention system).
- o The relative importance of system design factors and use influencing factors identified in this study and listed on the Tree.

Even if we accept that we have designed the most cost-effective system and have done an effective job of limiting side effects, we must still assure that the system will be operable and that it will be acceptable to the user. Evaluation of operability is reasonable straightforward based on NFPA sprinkler performance data. Evaluation of user acceptance

was done using the data base developed in this study.

In measuring the impact on humans, we must focus our emphasis on their ability to survive in the fire environment with the suppression system operating and not be harmed either by the discharging extinguishing agent or related combustion products.

Clearly, it would take much more time than is available today to explore each of these components in detail. Needless to say, in many cases all we could do was identify that we lacked an objective data base for precise quantification.

The degree of reduction in the National Fire Loss will depend on the number of residences protected with suppression systems. If all residences are so equipped, the reduction will exceed 50 per cent.

If systems are required in all new residential construction between now and 1990, the National Residential Fire Loss in 1990 can be reduced to 20 to 35 per cent, depending upon the cost of the system installed. With voluntary installation of systems (available at an installation cost of $.20 per square foot), the 1990 National Residential Fire Loss can be reduced by approximately 10 per cent.

The projected 1990 property loss is 1.13 billion. This could be reduced to as low as .8 billion, depending on how many systems are installed. Again, it must be emphasized that the numbers generated are dependent upon the data base and assumptions described in the complete report.

The cost projections (related to injuries) assume that a non-hospitalization injury will cost $25, a moderate injury $2000 with brief hospitalization, a serious injury $100,000 including hospitalization and rehabilitation, and a death $1,000,000. Since we could find no recognized validated study objectively establishing these costs, they were developed as a part of our study on the basis of the described assumptions. They should be considered in that light.

Automatic residential sprinkler systems, which are available today (Level I system), can significantly reduce the National Residential Fire Loss. If all residences are equipped with such systems, it is estimated that the reduction can be more than 50 per cent.

Sprinkler systems, as currently marketed, will not achieve this goal unless they can be installed at a significantly lower cost.

In existing residences, this means related costs of patching or painting walls, floors, or ceiling must be eliminated.

The least expensive sprinkler systems available today are not economically feasible in new single-family residences, because reduced construction costs, fire losses, insurance costs, and other benefits do not justify the investment in the view of the potential users.

In multiple family residences and new single residential developments (e.g., large projects) sprinkler systems may be cost-effective where building code land use or other alternatives permit construction cost savings comparable to the cost of the sprinkler system.

The major factors which may improve system acceptance are; in order of priority:

- Development of a "package system" for retrofit which can be installed without opening the finished walls.
- Development of installation incentives to reduce net cost, such as tax or insurance savings.
- Development of less expensive systems by reducing labor and hardware costs, rate and amount of water needed.
- Development of flexible piping to reduce the labor needed to install a system.
- Development of a system components designed for use in residential occupancies.
- Removal of restrictions to installations -- such as requirements for metering, backflow prevention and excessive permit fees.
- Development of more efficient (less water, better extinguishment) and responsive (faster operating) sprinklers.
- Improving the appearance of sprinklers.
- Teaching the public that there is a residential fire problem and that a suppression system will control residential fire without excessive water damage.

Many people are at work on these problems -- some funded by USFA, and other government agencies -- some not funded.

In addition, the NFPA sprinkler subcommittee is working on revisions to 13-D and fire tests, and other studies are filling our information gaps as you will hear from other speakers this morning.

IDENTIFICATION AND EVALUATION OF CURRENT BUILDING AND FIRE PREVENTION CODE ADMINISTRATION AND ENFORCEMENT PROGRAMS WHICH ARE PARTICULARLY IMPORTANT

By

Building Technology

David B. Hattis

"IDENTIFICATION AND EVALUATION OF CURRENT BUILDING AND FIRE PREVENTION CODE ADMINISTRATION AND ENFORCEMENT PROGRAMS WHICH ARE PARTICULARY EFFECTIVE"

Project Synopsis

The referenced contract was awarded by NFPCA in early 1978 to Building Technology, Inc. of Silver Spring, Maryland. Key personnel identified in the contract are: David B. Hattis of Building Technology, Inc.; Melvyn Green of Melvyn Green & Associates, Inc. and John G. Degenkolb, both of California. It is expected that work will be completed in early 1979.

The study is being carried out in accordance with Section 12 of the Federal Fire Prevention and Control Act of 1974, authorizing the review, evaluation and suggestions of improvements in state and local fire prevention codes, building codes and any relevant Federal or private codes and regulations. It is intended that the study's final report serve as a foundation for the preparation of general recommendations for improvement in code administration and enforcement (CA&E) and for the development of model CA&E program(s).

The approach taken to the study considers the full range of CA&E activities related to fire safety in both new and existing buildings. It includes the enforcement of zoning regulations, building codes, fire prevention codes, housing codes and health codes. In analyzing such a broad range of CA&E activities, the study is examining the organization and methods of the various units of government responsibile for the activities, the relationships between them, the relationships of their CA&E activity to their other activities, if any, and the attitudes of government personnel and others involved in the CA&E activities.

The analysis of CA&E programs is being carried out in communities which have apparently effective programs. These communities were selected from lists developed by nationally recognized organizations and individuals active in the code enforcement and fire prevention fields, prepared in response to a request to identify communities with "effective" or "innovative" programs. These communities were subjected to an analysis of their physical, social and governmental characteristics, so that a broad representation of community types would be surveyed. The resultant nine communities, in order of population size, are: Houston, TX; Portland, OR; Birmingham, AL; Wayne Township, IN; Santa Ana, CA; Bloomington, MN; Ogden, UT; Dover Township, NJ; Elk Grove Village, IL.

In addition to the population, geographic and climatic distribution, these communities represent a range of age, development patterns and land uses. They include a variety of forms of municipal government, paid and volunteer fire departments, and differences in the codes being enforced (statewide codes, model codes, etc.).

Researchers spent about a week in each community collecting data and interviewing government employees (from the mayor or city manager to the fire inspector), and private sector individuals. The interviews were based on pre-established uniform interview guidelines. The data are being organized into a detailed case study report for each community.

Subsequent tasks are:

- CA&E program analysis and evaluation
- Transferrability of CA&E programs or program features
- Development of the minimum number of model CA&E programs
- Identification of criteria for successful CA&E programs.

APPENDIX A:

LIST OF CONFERENCE ATTENDEES

Appendix A

REGULATORY IMPACT PROGRAM CONFERENCE

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NFPCA regulatory impact
programs conference ¦p
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